Policy Studies Journal, Vol. 28, No. 2, 2000 (313–328)

System Development in the Federal Government: How Technology Influences Outcomes

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Institutional analyses of federal programs to develop large technical systems explain outcomes in terms of a conflict between coalitional politics and program administration. Such analyses gain precision when they take into account how the technical system being developed mediates the conflict of politics and administration. Attention to technology helps explain the different outcomes of three federal programs: the superconducting supercollider, the space shuttle, and intelligent transportation systems.

Since the 1960s the U.S. government has undertaken numerous development programs in large technical systems. These systems have been diverse, ranging from weapon systems (Fox, 1988; McNaugher, 1989; Sapolsky, 1972) and space transportation systems (Casamayou, 1993; Jensen, 1996; Kay, 1994; Logsdon, 1986b; McCurdy, 1993; Vaughan, 1996) to supersonic commercial jets (Horwitch, 1982) and surface transportation systems (Burke, 1979; Lambright, 1976). Although there have been successes—most notably NASA's Apollo program (Sayles & Chandler, 1971)—many programs have fared poorly. They have often failed to achieve their goals, have developed technology that functions poorly, or have been abandoned before completion (Cohen & Noll, 1991; Desai & Crow, 1983).

A number of social scientists have sought to explain these outcomes from an institutional perspective (Cohen & Noll, 1991; Lambright, 1976; McNaugher, 1989; Sapolsky, 1987). They argue that the disappointing outcomes reflect a conflict between the coalitional politics of U.S. institutions and the administrative requirements of system development programs. On the one hand America's political institutions allow many groups to impose claims on spending programs, a phenomenon that has long attracted the interest of political scientists. Political support for programs requires satisfying the interests of a broad coalition of actors (Fenno, 1966; Ferejohn, 1974; Lowi, 1979; Wildavsky, 1974). On the other hand program administrators need a high degree of discretion in order to explore alternate development paths (Klein, 1968; Scherer, 1984). When program administration is subjected to coalitional politics, it suffers both from the pull of political forces and from a loss of flexibility for technological exploration.

Despite its power the institutional approach suffers from a lack of precision. Since politics conflicts with administration in *all* system development programs, the anticipated outcomes are always the same: "American political institutions introduce predictable, systematic biases in R&D programs so that, on balance, government projects will be susceptible to performance underruns and cost overruns" (Cohen & Noll, 1991, p. 53). The institutional approach cannot be more precise, because it neglects factors specific to individual programs. Likewise, institutionalists' policy prescriptions are broad, consisting of proposals to either redesign U.S. political institutions, to cease developing technology, or to expect more unsatisfactory outcomes (Cohen & Noll, 1991; Lambright, Crow, & Shangraw, 1988).

Without disputing these broad conclusions, one can seek more precision in explaining outcomes. In what follows I propose an addition to the institutional approach that allows for distinctions to be drawn between programs. I argue that the *technology*—the particular large technical system under development—mediates institutional effects. Characteristics of the large technical system may facilitate or impede the coalitional politics, thereby reducing or exacerbating the conflict between politics and administration. This focus on technology helps explain variations in programs outcomes.

Attention to the influence of technology is consistent with recent literature. A growing body of public administration literature examines the interactions of systems and complex organizations (Demchak, 1991, 1996; LaPorte, 1988, 1996; Perrow, 1984; Rochlin, 1993). Perrow (1984) identifies technology as a factor in system accidents, and Demchak (1991, 1996) argues that technology contributes to organizations' loss of adaptability to contingent events. Scholars in the sociology of technology have also addressed the role of the artifact in technology development (Bijker, Hughes, & Pinch, 1987; Mayntz & Hughes, 1988). Callon (1987) conceptualizes development in terms of "actor networks" in which the "actors" may be social agents, such as consumers, organizations, or social movements, but also may be components of a system under development, such as fuel cells or batteries. Both these groups of scholars are noteworthy for the inclusion of technology in their analyses. However, public administration scholars largely have focused on the administrative problems of operational systems, and sociologists of technology largely have examined coalitional politics outside of U.S. institutions. In this article I apply their insights about technology to the questions raised by institutionalists about federal programs for system development.

In what follows I begin by characterizing the political forces in U.S. institutions and identifying the kinds of conflicts that arise with program administration. This helps us recognize the characteristics of the technological artifact that can exacerbate or alleviate conflict. Next I examine the role of technology in the divergent outcomes of three programs: the superconducting supercollider (SSC), the space shuttle, and intelligent transportation systems (ITS). I conclude by identifying specific characteristics of large technical systems that alleviate the conflict of politics and program administration.

Politics, Administration, and Technology

The openness of U.S. political institutions allows a large number of actors to participate in policymaking. In policies for large technical systems, these actors usually include members of Congress, the Office of the President, executive agencies, the research community, and industry (Cohen & Noll, 1991; Hamlett, 1992; Lambright, 1994). Program advocates must build broad coalitions of these actors to launch their programs. Managers of ongoing programs must maintain broad coalitions of these actors to ensure continued funding.

Coalitions in U.S. institutions manifest recurrent patterns of interests—what I here call "political forces." Political forces take three general forms: geographic distribution, multifunctionality, and budgetary uncertainty. Each of them can conflict with program administration.

Political forces for geographic distribution arise from the American system of representative democracy. Elected from geographically defined districts, members of Congress often serve their constituents by channeling funds to those districts (Ferejohn, 1974). Likewise, presidents may have geographical commitments to their home state, to important electoral districts, or to "swing states" in upcoming elections (Logsdon, 1986b). To accommodate political forces for geographic distribution, program managers often distribute spending across the country. However, when development tasks are parceled out around the nation, administrative problems can arise. Coordination of distributed activities may prove difficult, "pork barrel" projects added to achieve distributional equity may cause budget overruns, and so on. Nonetheless, the alternative may be even worse. Programs that fail to accommodate these political forces may not be approved or may lose their funding during development.

The second kind of political force relates to functionality. Agencies have particular missions or functions to which they remain committed—what Heclo (1986) calls "functional localism." Researchers and industry suppliers may support a program only if it includes their particular expertise or products, and this can translate into demands for system functions. To attract political support from these actors, program managers often add functions to their system—an accommodation that, again, can undermine development. Some functions may push the limits of available technology, increasing risks and jeopardizing the success of the program. Others may be achievable only at very high cost—a phenomenon known as "gold plating" (McNaugher, 1989). Overall, a proliferation of functionality may increase technical and managerial complexity. Nonetheless, programs that do not accommodate political forces for multifunctionality may fail to attract a broad coalition.

The third political force reflects the dynamics of budgets over time. During its years of development, a program's funding may oscillate unpredictably. The salience of some tangentially related issue may increase or decline, the federal budget may shrink or expand, and any number of unforeseeable developments could occur that affect a program's budget. As a result, program funding may exhibit a boom-bust character (Cohen & Noll, 1991). Managers have to adapt their programs as best they can. When funding suddenly declines, development may have to be scaled down, systems may have to have their functionality reduced, or program spending may have to be stretched out over time. Even a sudden upsurge in funding can cause difficulties as managers scramble to increase spending so as not to lose funding. Like the political forces for geographic distribution and multifunctionality, unstable budgets can undermine administration.

These three political forces define a greatly simplified model of technological politics in U.S. institutions. No claim is made here that these three forces are either mutually exclusive or collectively exhaustive. For example, forces for geographic distribution may result in a certain vendor receiving a contract, which, in turn, requires that a certain functionality be incorporated into a system. However, the three types of political forces here are common to most programs.

The resulting conflicts lead to unsatisfactory outcomes. Defense systems are overly complex, expensive, and unreliable (McNaugher, 1989). Civilian systems exhibit poor performance characteristics and excessive costs (Cohen & Noll, 1991). The details vary from program to program, but their common characteristic is suboptimal technology and a recognized failure to achieve program goals.

Although writers employing the institutional perspective do not make the distinction explicitly, program outcomes can be grouped into two types: *political failure* and *technical dysfunction*. In the case of political failure, a program's supporting coalition falls apart, and it loses its budget and is canceled. For example, when the coalition supporting the SSC fell apart in 1993, the program's funding was cut off and development ended abruptly (Idelson, 1992). The supersonic transport (SST) also experienced political failure, with Congress terminating the program in 1971 (Horwitch, 1982). In the case of technical dysfunction, a program produces a system that fails to perform as intended. Program managers *knowingly* compromise their technology, trading off decreased system performance for increased political support. McNaugher (1989) documents numerous fully developed but dysfunctional systems in the defense sector, including the C-5A transport plane (whose wings cracked) and the Sergeant York gun (that entered production but didn't work.)

This categorization of outcomes into just two types reflects the limitations of the institutionalist approach, which, as noted above, offers very general insights. Yet outcomes do vary. Although political failure is an absolute, programs do vary in their degree of technical dysfunction—and some even produce quite functional systems (Cohen & Noll, 1991). By examining how technology mediates the conflict of politics and administration, we can better understand this variability in outcomes.

Politics and technology are linked. The linkages occur when program administrators translate political forces into design parameters, accommodating interests by modifying the system under development. Each of the three political forces described above can be translated into a design parameter. Political forces for geographic distribution can be accommodated by a system design that distributes components or their development geographically. Political forces for multifunctionality can be accommodated by a design that incorporates heterogeneous functions. Political forces of budgetary instability can be accommodated by a flexible design that allows for midcourse expansion or contraction. Clearly, the ability to incorporate such design features cannot guarantee political success, but it can reduce the conflict between politics and administration.

Conversely, an *inability* to incorporate such design features can exacerbate conflict. Unfortunately for some program managers, some systems may have a structure that renders them unable to incorporate politically desirable features. Perrow (1984) notes that we have comparatively little choice in the design of some of our systems. Development may require that all components lie in close proximity or be developed on site. A system's functionality may be so specialized as to preclude the addition of new functions. The schedule of program spending may allow for little modification once begun. In such systems the accommodation of political forces may be impossible or may be achieved only by ignoring the constraints and accepting the resulting problems. In these cases the problems documented by the institutionalists arise: programs experience either political failure or technical dysfunction.

By recognizing the role of technology in the accommodation of political forces—and by recognizing differences among technologies in their ability to allow such accommodation—we can better understand why program outcomes vary. What follows are accounts of the federal programs for the SSC, the space shuttle, and ITS. Each program was subject to predictable patterns of political forces, yet their respective technologies differed in the degree of design choice they made possible. These differences in technology help account for the differences in outcomes.

The SSC

The history of the SSC illustrates one type of outcome: political failure. After years of development and billions of dollars of spending by the Department of Energy (DOE), the program's supporting coalition declined to the point where its budget was cut. The technology of the SSC imposed such strict design requirements that program managers could not satisfactorily accommodate the interests of a broad coalition.

Although an instrument for the conduct of basic research, the SSC was itself a large and complex technical system. Its function was to accelerate elementary particles and collide them with other particles to investigate the interactions. To do this it used a ring of magnets to accelerate a stream of charged particles to higher and higher energies until brought into collision. Similar devices had been built since the 1930s (Childs, 1968; Jachim, 1971; Lowi, 1976), but the SSC was to be the largest ever, with a circumference of 54 miles.

The origins of the program to develop the SSC date back to the early 1980s, when the ideas of physics researchers won the support of President Reagan's scientific advisor, George Keyworth (Ritson, 1993). In 1984 the DOE approved the creation of an expert group to draw up a detailed SSC proposal, which was ready 2 years later. Then, shortly after the election of President Bush in 1988, a site in Texas was selected, and in June 1989 the first construction funds were budgeted by Congress. Construction of the SSC ran for some 3 years, during which $1.8 billion was spent on the project. The program was canceled in 1993.

During its abbreviated lifetime the SSC proved ill-suited to accommodate the political forces in U.S. institutions. Demands for geographic distribution proved the most problematic. Program managers attempted to achieve distributional equity by spreading procurement contracts widely, and by 1992 45 of 50 states participated in some manner in SSC construction activity (Idelson, 1992). Reflecting common practice, the largest procurements were channeled toward the home states of members of Congress with the greatest influence over the program. In a telling episode from the early phase of the program, the General Dynamics Corporation publicized its intention to build a magnet plant in the home state of the chairman of the Senate Energy Committee, who shortly thereafter shifted his position from one of skepticism to strong support for the program (Kuntz, 1990).

Still, most federal funds had to go to the one state where the accelerator would be built. The technology of particle acceleration dictated that the SSC be located in one site, which led to an unavoidable concentration of construction spending. Given this technical constraint, program managers selected a site in Texas, the state with the most powerful political delegation in Washington. Two days after George Bush won the 1988 presidential election, the DOE selected a site in the President's home state. Texas also had a powerful congressional delegation that included Speaker of the House Jim Wright and Senator Lloyd Benson, chairman of the Senate Finance Committee (Taubes, 1993). President Bush quickly became an energetic supporter, pushing Congress to initiate the large-scale construction funding that started in 1989. As even sympathetic observers noted, the political clout of Texas influenced the decision (Ritson, 1993).

Predictably, Texas received the lion's share of federal funds. From 1989 to 1992 nearly half of all construction spending ($200 million) went to that one state, with the next biggest recipient, California, receiving only a quarter of that amount ($54 million) and most others far less (Idelson, 1992). Members of Congress from other states lost interest as the program failed to distribute major resources to their districts, and critics denounced it as a pork barrel project for Texas (Mills, 1993). The problem was not Texas per se, however, but the fact that spending was lopsided. Even if the site had been elsewhere, the problem would not have disappeared. The unalterable spatial characteristics of the SSC's system design conflicted with political forces for geographic distribution.

The characteristics of the SSC also conflicted with political forces for *multifunctionality*. The SSC was designed to perform one specialized function: particle acceleration/collision. This served well the needs of researchers in one scientific specialty, high-energy physics, and it also contributed to the mission of one federal agency, the DOE. However, a multibillion dollar program needed a wider base of support than this. To broaden the supporting coalition, SSC advocates attempted to expand its functionality. In this endeavor they had little success, however, because the SSC simply could not incorporate additional functions. Instead, expansion was attempted through rhetoric. Advocates claimed that the SSC's functionality would contribute to educational, research, and economic goals. As a symbol the SSC would inspire young Americans to study science and technology, and as a research tool it would broadly strengthen basic research in the United States (Grad, 1990). Spin-offs would contribute to the long-term growth of U.S. technology (Ritson, 1993).

The SSC was ill-suited to supporting even such rhetorical claims, however. Its atom-smashing capabilities were of little interest to other fields of research, whereas its multibillion dollar budget caused other scientists to fear that it would crowd out other research funding (Idelson, 1992). These fears were bolstered when the House of Representatives limited the National Science Foundation research budget even as they approved construction funds for the SSC (Cordes, 1989). Even broad claims about competitiveness were criticized in a 1988 Congressional Budget Office study (Congressional Budget Office, 1988). The SSC was simply too specialized a device to satisfy the functional needs of other groups.

Budgetary *instability*, the third political force commonly acting on programs, also proved difficult to accommodate. In 1993, with support for the program growing thin, the Clinton administration proposed to stretch out SSC construction, to lower annual costs. However, because of the high fixed costs of such a massive construction project, this delay would have added $2 billion to the final price. Instead of attempting to lower costs, program managers actually increased the rate of spending in an attempt to cross a "point of no return" in spending (Ritson, 1993). This attempt to cope with budgetary instability through direct defiance, although not unknown as a strategy in budget politics (Wildavsky, 1974), also reflected managers' limited opportunities for midcourse redesigns. The technology of the SSC simply did not lend itself to such adaptations.

With the SSC unable to accommodate the interests of many actors, the coalition supporting the program steadily weakened. The problem worsened as the Texas politicians declined in power, losing the White House, the leadership of the

House of Representatives, and the leadership of a Senate committee. In 1992 the House of Representatives voted to cancel the program, but the Senate restored the funding and prevailed in the final budget. In 1993, after a similar split between the two chambers of Congress and under a new president, the House prevailed and the program was terminated.

To explain this outcome one need not look to shifts in the salient goals of elected officials (e.g. Jones, 1994), for the decision was consistent with an enduring concern with distributional and other benefits. Likewise, problems in program management, although serious (Anderson, 1993), did not distinguish the SSC from other federal system development programs. The SSC program received unique treatment as a result of its inability to serve the interests of a broad array of political actors. Even as the House members made their first vote against SSC, they gave continued support for programs in nuclear power technology, a space power system, and a variety of water projects (Idelson, 1992).

One implication of the technology argument advanced here is that the problems of the SSC would be expected to undermine any federal program for a particle accelerator, since any accelerator would have similar technical characteristics. Indeed, the SSC was not the first accelerator program to suffer political failure. Ten years earlier the Brookhaven national laboratory's accelerator had also been canceled, leaving behind a "$200 million concrete doughnut" and a deeply disappointed New York congressional delegation (Grad, 1990; Ritson, 1993). Earlier accelerator siting decisions, although successful, also were characterized by highly politicized siting processes (Jachim, 1971; Lambright, 1985; Lowi, 1976).

The Space Shuttle

The National Aeronautics and Space Administration (NASA)'s space shuttle program also illustrates the conflict of politics and administration and the mediating role of technology. Here the technical system gave more design choice to program managers, enabling them to accommodate political forces to a greater degree than their SSC counterparts. Unfortunately, these accommodations ultimately exceeded what the system could bear, and the space shuttle *Challenger* failed disastrously in January 1986, grounding the entire program for nearly 3 years. NASA managers knowingly compromised their system to accommodate political demands, and the result was severe technical dysfunction.

A voluminous body of literature has documented the history of NASA, the Apollo program, and the space shuttle program (Barfield, 1972a, 1972b; Casamayou, 1993; Jensen, 1996; Logsdon, 1986a, 1986b; McConnell, 1987; McCurdy, 1993; Vaughan, 1996). The origins of the space shuttle date back to the late 1960s, when NASA began planning a follow-on to the Apollo program. Whereas the earlier program had benefited from an exceptional national commitment, the shuttle did not enjoy such strong support from the president or Congress. NASA had to engage in "normal" politics, building and maintaining a broad coalition of executive branch agencies, members of Congress, the president, and others in support of its new program (Lambright, 1992; Logsdon, 1986b).

Predictably, political forces for the geographic distribution came to bear on the program. Since the shuttle program was a successor to the Apollo program, many of the facilities for launching and tracking were already in place, the product of earlier processes of political wrangling over distributional benefits.

For example, shuttles were launched in Florida but were tracked from facilities located in Texas, the home state of President Johnson, who oversaw much of the Apollo program in the mid-1960s (Jensen, 1996). Still, the space shuttle required additional federal spending, and this was distributed with an eye toward political factors. Procurement contracts issued in 1972 were directed to key election-year states, a practice denounced by the Democratic national chairman as a "calculated use of the American taxpayers' dollars for [President Nixon's] own reelection purposes" (Barfield, 1972b). Major contracts were also channeled to Utah, the home state of both the NASA Administrator and the chairman of the Senate Committee on Aeronautical and Space Sciences (Jensen, 1996). The use of a Utah contractor may have made good political sense, but outside evaluators criticized it for undermining program administration. When Utah's Morton Thiokol Corporation received the rocket engines contract, rival Lockheed contested the decision, and eventually a board of appeals recommended that NASA reconsider its decision ("GAO investigates," 1986; Jensen, 1996). Nonetheless, the Utah supplier kept the award. Morton Thiokol's rocket engine design later proved to be one of the weakest components in the shuttle system and the one that ultimately caused the January 1986 disaster.

NASA also experienced powerful political forces for increased functionality. NASA considered the Department of Defense (DoD) a vital ally in its coalition, calculating that DoD support would attract congressional and presidential support. To make the shuttle appealing to the DoD, NASA added defense-related functionality. The DoD needed a shuttle that could carry payloads of up to 40,000 pounds in weight, a 60% increase over NASA's own projected payloads (Jensen, 1996). The DoD also needed a shuttle that was maneuverable enough to land at the same location from which it was launched and to fly 1,100 miles in a lateral ("cross-range") direction to avoid hostile territory (Logsdon, 1986b). The DoD requirements were so numerous—and the DoD's political support was so vital—that NASA Administrator James Fletcher (1971) estimated that the DoD set every crucial design parameter but one. In accommodating the DoD's interest in increased functionality, NASA designers encountered the limits of their technology. The cross-range functionality would expose the shuttle to more heat, which would require heavier thermal protection. In turn, the heavier thermal protection, combined with the DoD's payload weight requirements, would place additional demands on the propulsion system. New solid-fuel rocket engines had to be developed that combined low cost, low weight, and high power. This technological novelty added uncertainty to the system. The shuttle's safety abort features were also eliminated to reduce weight, and its speed and angle of landing were increased to allow for smaller wings (Jensen, 1996). To satisfy the interests of a coalition partner, NASA accepted an increase in technological uncertainty and a reduction in safety.

NASA also was buffeted by budgetary uncertainty, largely in the form of pressures to reduce costs. Initially, NASA reduced budgets by lopping off major system components. In 1969 the shuttle stood as one element in a comprehensive plan for a space station, shuttle, and lunar surface station (Barfield, 1972a). Under budgetary pressure NASA first reduced that to just a space station and a shuttle and then later to just a shuttle (Barfield, 1972a). With the system reduced to just the shuttle, however, budgetary pressures were less easy to accommodate. When the Office of Management and Budget (OMB) in 1971 capped NASA's budget at just half what it wanted, the shuttle itself underwent a major redesign. By switching to disposable components NASA lowered development costs in exchange for higher operational costs. NASA also publicly committed itself to paying for future operating costs with revenue from its commercial operations. The shuttle would be a "space truck" providing routine and affordable access to space (Jensen, 1996).

By accommodating political forces for geographic distribution, multifunctionality, and budgetary uncertainty, the program survived politically and became operational in 1981. Yet NASA had knowingly ignored the constraints imposed by the technology—with predictable results. The shuttle suffered from a variety of dysfunctions (Jensen, 1996). Thermal tiles fell off, threatening the crew with incineration upon reentry into the atmosphere. Brakes failed during high-speed landings. The hydraulic system caught fire. Engines failed. Computers failed. Gaskets leaked. Launches regularly suffered delay or cancellation.

Technical dysfunction could be ignored only for so long before asserting itself. In the years preceding the *Challenger* disaster, engineers had documented how rocket casings leaked when their O-ring gaskets grew stiff in cold weather, threatening "loss of mission, vehicle, and crew...." (*Report*, 1986). Redesigning the engines, however, would set back operations by months and would greatly weaken NASA's political support in Congress. This conflict between politics and technology was decided in favor of politics, and the known malfunction was allowed to continue. Finally, on a winter morning in 1986, a shuttle launch coincided with exceptionally cold weather. The *Challenger* experienced the system failure long anticipated by NASA engineers (Jensen, 1996).

The technology of the space shuttle limited the choices available to NASA. Forced to choose between sound administrative practice and the accommodation of political forces, NASA chose the latter. Predictably, the technology malfunctioned. With little tolerance for even minor problems, the entire system eventually failed. Arguably, those problems remain even today. Years after the *Challenger* disaster, analysts continued to warn NASA that its shuttle operations constituted a game of "Russian roulette" (Gleick, 1993).

The space shuttle and the SSC illustrate the two kinds of outcomes predicted by institutionalists. The shuttle successfully accommodated political forces, but in so doing developed a dysfunctional system. The SSC failed to accommodate political forces and experienced political failure. The system examined next shows that the conflict of politics and administration need not always be so severe. In the federal program to develop ITS, technology proved better able to accommodate political forces.

ITS

The U.S. Department of Transportation (DOT) program in ITS avoided the extreme outcomes of program termination or technical failure. Although developed in the same context as the shuttle and the SSC, its greater degree of success suggests that some systems are better able to accommodate political forces than others. A focus on the technology helps explain the program's outcome.

Although its proponents commonly referred to it in the singular (as I do here), ITS was really a family of subsystems joined in an overarching system architecture. ITS consisted of the application of information, communication, and automation technology to road transportation, to realize a variety of functional subsystems. One such subsystem was a digitized road map and computerized navigation system to guide drivers through street networks on the most efficient route to their destination. Another subsystem was adaptive traffic management in which in-road sensors measured vehicle flows and a central computer used those data to operate traffic signals and optimize traffic flows. Another subsystem was automated highways, which would allow "platoons" of vehicles to drive at high speed in close proximity to each other under automatic control, thereby increasing the traffic throughput of an urban highway. Dozens of other subsystems for private automobiles, transit vehicles, and commercial vehicles were foreseen in the 1991 strategic plan for the national program (IVHS America, 1991). While each of them was intended to deliver benefits of its own, their union in an integrated system was to yield additional benefits. For example, an in-vehicle navigation device would use congestion information from a traffic management system to compute the fastest route through rush hour traffic.

The national ITS program was first proposed around 1989 and was formally launched by the DOT in 1991 with approximately $1 billion of funding (Congressional Budget Office, 1995). At the time of this writing the program was still under way.

The same political forces that acted on the SSC and the space shuttle shaped the ITS program. Reflecting supporters' interest in geographic distribution, members of Congress inserted dozens of legislative earmarks in the ITS legislation to channel spending to their home districts. Local highway departments received federal funding for field tests, firms received procurement contracts, and research universities received research support. Influential legislators in New Jersey and Michigan oversaw the siting of especially large demonstration projects in their home states (Federal Highway Administration, 1998).

Coalition members' functional interests also came to bear on the program. The original ITS champions were two groups of researchers with interests in two kinds of functionality. Researchers at the University of California had expertise in vehicle automation technologies for high-speed highway driving. Their counterparts at the Federal Highway Administration (FHWA) were experts in the application of information technology for driver navigation. In 1989 the two groups joined together, proposing a system that would include automated highway driving *and* driver navigation. Although these functions were not immediately related to each other, they could coexist in a multifunctional system (Saxton, 1993; Shladover, Bushey, & Parsons, 1993). As the coalition further broadened to include three DOT agencies, additional functions were added to the system. The FHWA's interest in congestion reduction was satisfied with the addition of traffic management systems. The National Highway Transportation and Safety Administration's interest in road safety was satisfied by the addition of subsystems for collision avoidance. The Federal Transit Administration's (FTA's) interest in public transportation was satisfied by functions for electronic fare payment and fleet management. Defense interests, suffering from post-Cold War procurement cutbacks, also participated in the coalition. Twenty of the nation's largest defense contractors shared a contract to design an overall system architecture, a project that utilized their expertise in system analysis.

In some instances, forces for geographic distribution and multifunctionality combined. In its early conception ITS offered little utility for rural states and their representatives in Congress. However, the addition of specifically rural functions to the ITS design broadened its appeal (IVHS America, 1991). Rural subsystems included an emergency "Mayday" signal for isolated accidents and—in an extreme case of adding functions to accommodate interests—electronic "deer detection" for country roads.

Although budgetary instability had little impact on the initial program, in at least one instance ITS demonstrated its ability to accommodate budget reductions. When a field test of specially equipped vehicles in Chicago suffered a budget cut, it simply proceeded with a smaller vehicle fleet. Instead of 3,000 vehicles, the test employed just 75. The budget cut reduced the effectiveness of the test, but the program could adapt by scaling down the subsystem (Illinois Department of Transportation, 1997). System development continued, Illinois got its field test, and spending was reduced—and any conflict among interested parties was minimized.

Although by 1999 ITS development was not complete, the intermediate outcome of the program suggested a mixed result. Some subsystems experienced political failure. Local transportation officials expressed strong skepticism about the feasibility of constructing automated highways, and shortly after a field test in 1997 the federally funded consortium disbanded (National Automated Highway Systems Consortium, 1998). A field test using mobile communications for re-routing buses according to traffic conditions was canceled after the first of two phases (Federal Highway Administration, 1998), yet other subsystems proved more successful. Traffic surveillance and management systems demonstrated success in Maryland and became a priority area for nationwide development (Klein, 1996). In-vehicle navigation devices, developed in the private sector but with public support, began to appear in rental cars. Electronic toll payment systems were implemented throughout the United States. Thus although some subsystems functioned poorly, others showed promise. Although it would be an exaggeration to claim that the program was an unqualified success, it avoided the SSC's decisive political failure and the shuttle's massive technical dysfunction.

The ITS program's mixed success resulted in part from the technology's ability to accommodate nearly all demands placed on it. The base technologies proved extremely malleable, allowing for the geographic distribution of field tests, the addition of a variety of heterogeneous functions, and the adjustment of budgets as larger forces dictated. The relative autonomy of dozens of subsystems and field tests insulated them from each other so that technical dysfunction in one part of the system did not undermine other parts.

Conclusions

When a development program can satisfy the interests of a broad coalition without compromising sound development practice, it can both survive politically and succeed technically. The three cases above illustrate how programs differ in this capability. All of them experienced similar political forces, but their outcomes varied. These differences in outcomes reflect, in part, differences in the technology under development. The technology of ITS could better accommodate political forces than could the SSC, and it could better withstand technical compromises than could the shuttle.

We conclude by identifying four characteristics of technical systems that render them better able to survive the politics in U.S. institutions. (No claim is made that the list is exhaustive.) These characteristics reduce constraints on program managers' accommodation of political forces for geographic distribution, multifunctionality, and budgetary instability. They are: *ramification*, *aggregation*, *granularity*, and *modularity*.

We conceive of coalition building as a process in which unforeseen interest-based demands accrue over time and impose new design parameters on a system. This can be conceived as either a top-down or a bottom-up process. In the top-down conception, an initial system design expands to accommodate interests. To do this the technology must be capable of *ramification*. Following its initial conception, a system must be capable of expanding in new directions, articulating new functions, and occupying new sites as demanded by coalition members. For example, the space shuttle was conceived originally as a simple support vehicle for NASA's larger mission, but it blossomed into a multifunctional system serving the DoD's needs. Similarly, when the FTA joined the ITS coalition, the technology could ramify from highway functionality into transit functionality. When rural interests joined the ITS coalition, the technology could ramify into rural locations. In all these cases the initial conception of the technology could expand.

Ramification may be achieved more easily when the technology in question is conceived abstractly. The ITS program sought to develop "information technology" applications in transportation rather than any single system. As new actors entered the supporting coalition, specific applications were conceived that satisfied their interests. The abstract conception of the technology allowed for ramification into many specific systems.

In the bottom-up conception, a system may support a coalition through *aggregation*. Political actors enter a coalition already supporting some technology. In the coalition they join other actors who also support particular technologies. As the actors join together, their technologies are aggregated. For example, the earliest coalition building in the ITS program saw proponents of automated highways join with proponents of driver information systems, uniting their heterogeneous technologies. The technology allowed for the aggregation of diverse components.

Such aggregation of technologies, with its basis in the political domain, may lead to claims about "systems." A heterogeneous collection of different technologies may be presented as a system, when in fact it is the by-product of a coalition. Technologies with little relationship with each other may be united into a system. The ability to perform such aggregation, however, may be a major contributor to political success. Technologies that allow for aggregation may fare better in political processes.

Even when successfully supported by a coalition, budgetary instability may require changes in the scale of a program. Here a desirable property of a technology is *granularity*. When a system is composed of many parts, or "grains," then some can be eliminated in lean times. Large grains might be subsystems; smaller grains might be field tests or functions within a subsystem. When budgets contract, some of the grains can be eliminated without eliminating the entire system or subsystem. As noted above, an ITS field test could shrink substantially and still survive by reducing the number of vehicles (grains) in its test fleet from 3,000 to 75. Systems with little granularity may impose an all-or-nothing choice on budgetmakers, with the attendant risk of complete termination.

A final characteristic of a technical system helps avoid total failure. As a system accommodates geographical, functional, and budgetary forces, some dysfunction is likely. Some subsystems may be too dispersed geographically to interact effectively; some functions may exceed the capabilities of available technology; some field tests may be too small to be reliable. It is important that dysfunctional components or subsystems not undermine the full system. A characteristic of the technology that inhibits this is *modularity*. Modules have well-defined interfaces and some stand-alone functionality so they can survive the failure of another module and keep working. When components and subsystems exist as semiautonomous modules, then the failure of one is less likely to undermine others.

Systems with all these characteristics can be called *coalitional systems*. The technical system can mirror the social system that develops it. By ramifying from an initial design or aggregating multiple subsystems, a system can attract coalitions. With its granularity it can scale up or down without terminating. With its modularity, its can contain dysfunction.

The identification of these characteristics allows for some broad insights about federal system development programs. First, some technologies may fare better than others. For example, computer software possesses most of these characteristics, while aerospace technology possesses fewer. A software system can ramify into new functions, can be tested in many locations, and can be made modular. It can scale down piece-wise if necessary. Aerospace systems, on the other hand, often lack such characteristics. There the artifact is subject to tight constraints on volume and weight, so growth through ramification or aggregation may be constrained. Modularity may be difficult if it increases the weight and space of the component.

A second insight concerns national prestige. National prestige is often cited as a factor favoring grand technology projects (Logsdon, 1986b). It has figured prominently in the Apollo and shuttle programs and in the SSC. Yet the kind of system that boosts prestige is often a big, integrated machine of some sort—a rocket, an atom smasher, a supersonic transport. The kind of technology that works well in the U.S. political system, however, is granular, modular, multifunctional, and distributed. These characteristics may offer little in the way of symbolism and prestige. Projects that support national prestige may be the most likely to fail.

In summary, the institutional perspective on large technical systems can be enhanced by taking into account the influence of technology. Although all federal system development programs unfold in the context of U.S. political institutions, they vary in their outcomes. As the cases above illustrate, that variation reflects differences in technology of the systems themselves. Technologies capable of *ramification* and *aggregation* can attract coalitions. Technologies that are *granular* can scale down during budgetary reductions. Technologies that are *modular* can contain dysfunction and avoid total system failure. ITS had all these characteristics. The space shuttle had some. The SSC had practically none.

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Notes

The author thanks Barry Bozeman, David Roessner, and Ximena Leroux for their helpful comments and Oren Grad for suggesting research sources.

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